LLNL-PRES-685501

NCSP
NUCLEAR CRITICALITY SAFETY PROGRAM

CED-1 for Thermal/Epithermal Experiments (TEX) with Highly Enriched Uranium Jemima Plates with Polyethylene and Hafnium

Presented at the Nuclear Criticality Safety Program (NCSP) Technical Program Review
March 15-16, 2016 at Sandia National Laboratories, Albuquerque, NM

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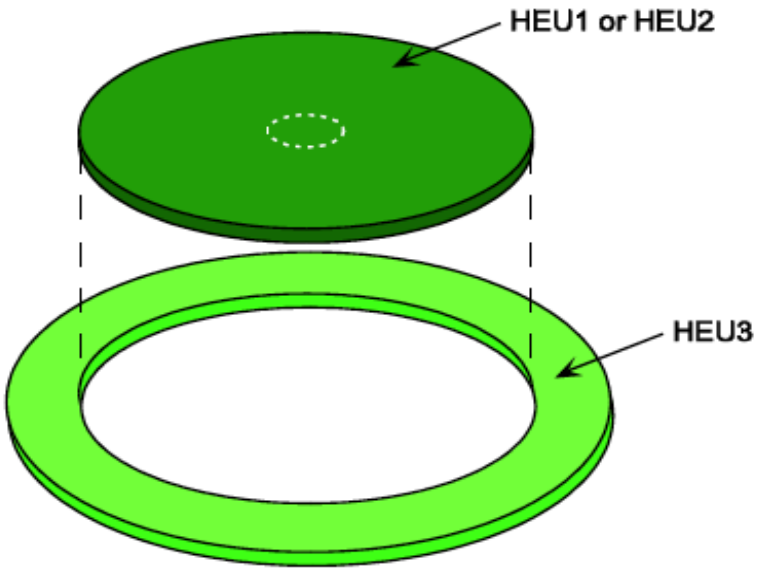
IER 184: Thermal/Epithermal eXperiments (TEX)

- TEX Feasibility Meeting
  - July 2011 at Sandia National Laboratories, Albuquerque, NM
  - Representatives from US, UK, and France
- Intermediate spectrum experiments needed (0.625 eV-100 keV)
  - Limited Data (2.1% of ICSBEP Benchmarks)
  - Consensus prioritization of nuclear data needs (in order):
    - ^{239}Pu, ^{240}Pu, **^{238}U, ^{235}U**, Temperature variations, Water density variations, Steel, Lead (reflection), **Hafnium**, Tantalum, Tungsten, Nickel, Molybdenum, Chromium, Manganese, Copper, Vanadium, Titanium, and Concrete (reflection, characterization, and water content)
- Preliminary Design (FY12) showed feasibility for three different fissile systems to create intermediate energy assemblies with various diluent materials
  - Further calculations with HEU Jemima Plates moderated by polyethylene with hafnium diluents were necessary

Parameter Study Materials

- Jemima Plates
  - Existing U.S. Asset at NCERC
  - 3 mm thick
  - 15” diameter, range of central cylindrical holes (2.51”, 6”, and 10” diameter, 6.3754, 15.24, and 25.4 cm)
- Hafnium Plates
  - Need to be fabricated
  - Outer diameter match Jemima Plates (15”, 38.1 cm)
  - Find Optimal thickness (0.5 to 3 mm, 0.0197 to 0.1181”)
- Polyethylene Plates
  - Need to be fabricated
  - Outer diameter match Jemima Plates (15”, 38.1 cm)
  - Vary in thickness from 1/16” to 1” (0.159 to 2.54) to tune neutron energy spectrum

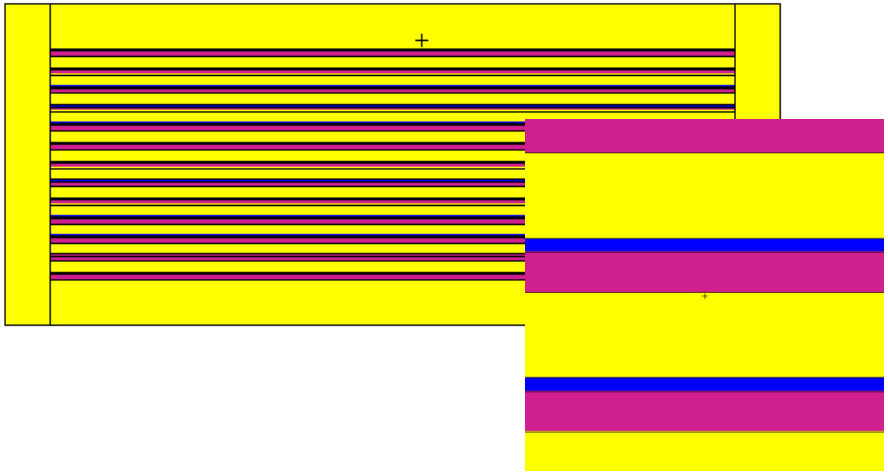


Goals for CED-1 Addendum

- Undertake a parameter study to determine the optimal Hf plate thickness with three major design criteria:
  - Create thermal, intermediate, and fast critical configurations
  - Assemblies with a height to diameter ratio of about 1
  - Maximizing sensitivity to hafnium isotope cross sections

Scoping Parametric Models

- Models developed with Scale 6.1/Keno V.a using ENDF/B-VII.0 continuous energy cross sections
- Vary Hf thickness between 0.5 to 3 mm with 0.5 mm increments
- Vary PE thickness from 1/16” to 1” in 1/16” increments
- Two stacking methods, Standard and Sandwich



Standard Stacking Model
Yellow: PE (0.25”, 0.635 cm)
Blue: Hf (.039”, 0.1 cm)
Pink: HEU (0.118”, 0.3 cm)

Sandwich Stacking Model
Yellow: PE (0.25”, 0.635 cm)
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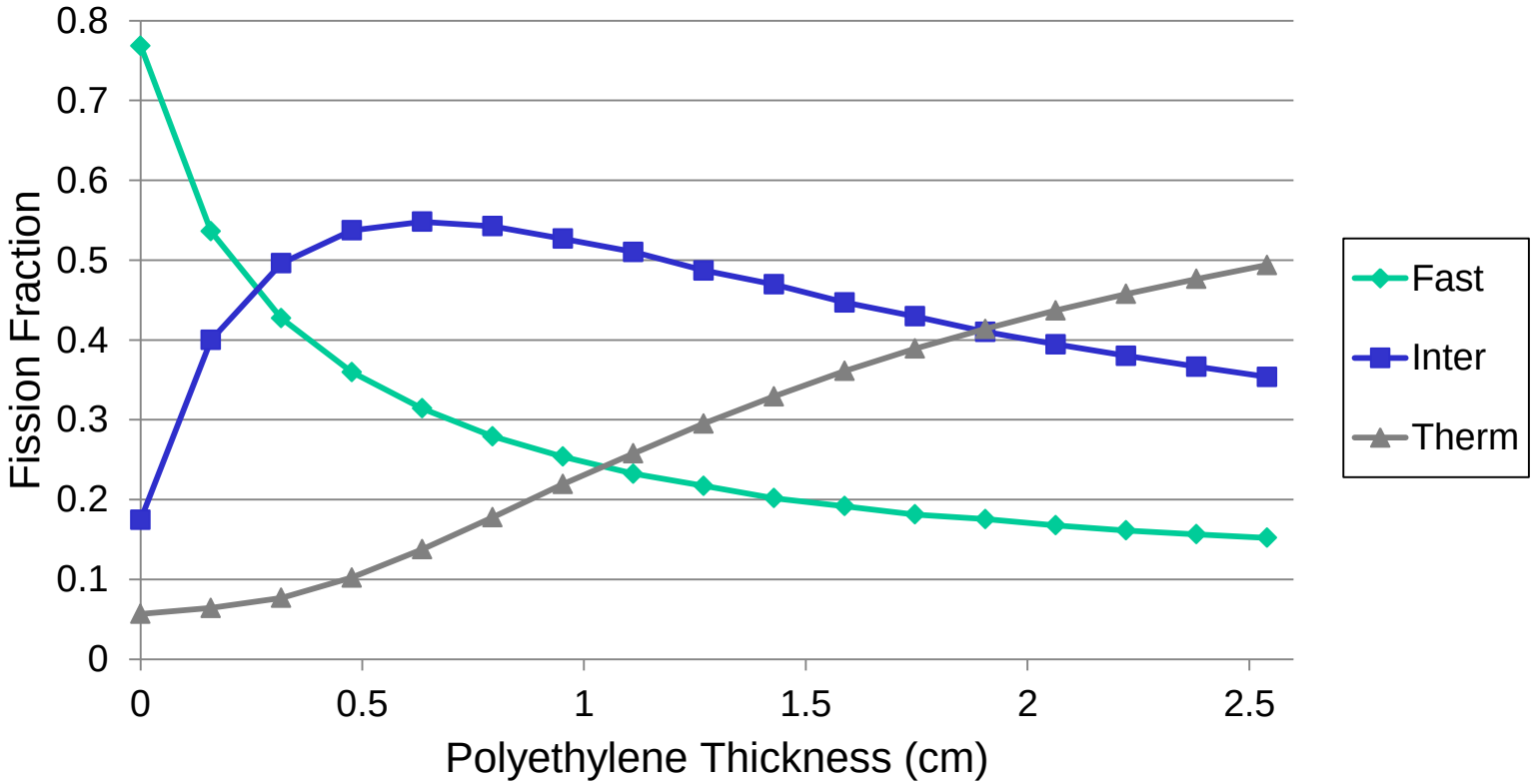
Example Data from Parameter Study

Fission Fractions for Neutron Energy Groups as a Function of Polyethylene Thickness with the Standard Stacking Configuration and 0.10 cm Hf Thickness



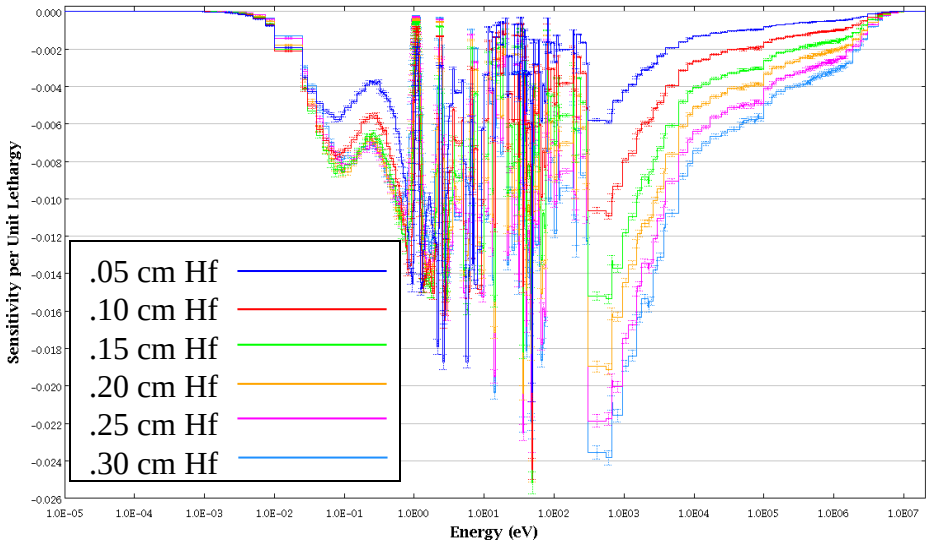
Summary of Maximums

		Fission Fraction Maximum			Maximum		
Hf Thickness (cm)	**Stacking Method**	**Fast**	**Inter**	**Thermal**	**U (kg)**	**Hf (kg)**	**Height (cm)**
0.05	Standard	0.757	0.538	0.512	107.9	13.66	19.88
0.05	Sandwich	0.744	0.555	0.451	107.9	12.90	22.72
0.10	Standard	0.769	0.548	0.494	113.9	28.83	26.06
0.10	Sandwich	0.744	0.568	0.420	107.9	25.80	34.78
0.15	Standard	0.777	0.555	0.479	119.9	45.53	35.43
0.15	Sandwich	0.749	0.578	0.401	113.9	40.97	56.21
0.20	Standard	0.783	0.558	0.468	125.9	63.73	54.22
0.20	Sandwich	0.754	0.586	0.367	227.8	112.3	112.0
0.25	Standard	0.788	0.564	0.455	407.7	258.0	212.7
0.25	Sandwich	0.758	0.592	0.291	335.8	208.7	140.4
0.30	Standard	0.791	0.566	0.361	431.7	327.8	183.5

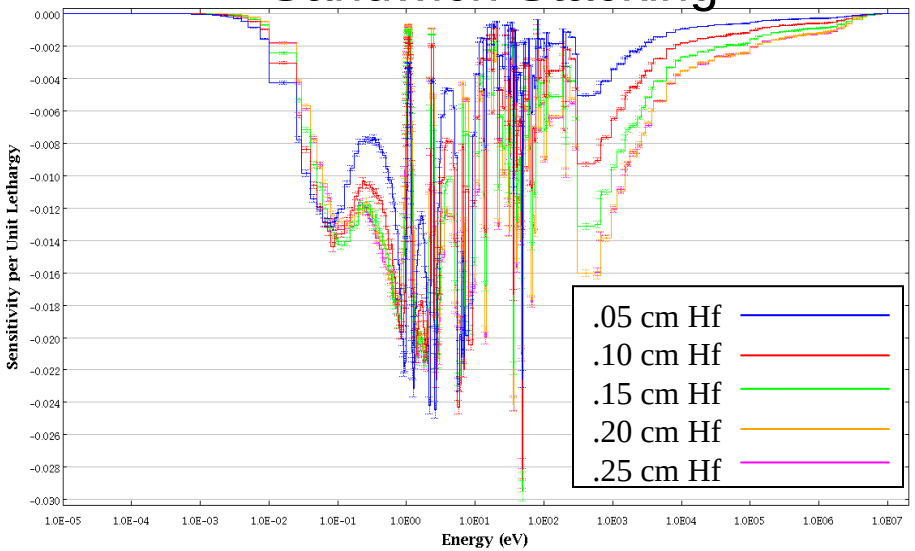
*** Insufficient Jemima plate mass available for RED configurations**

Hafnium Sensitivity- TSUNAMI 238-ENDF/B-VII.0

Standard Stacking



Sandwich Stacking



Hf Capture	total	fast %	inter %	therm %	Hf Mass
0.05 std	0.071	2.499	41.84	56.40	8.35
0.10 std	0.101	3.580	50.13	47.33	19.73
0.15 std	0.124	4.498	56.99	39.83	34.14
0.20 std	0.139	5.277	61.96	34.30	48.56
0.25 std	0.154	5.917	66.11	29.69	72.08
0.30 std	0.164	6.674	68.92	26.32	95.60

Hf Capture	total	fast %	inter %	therm %	Mass Hf
.05 sand	0.098	1.052	29.71	69.55	7.59
.10 sand	0.122	1.714	37.92	60.88	18.21
.15 sand	0.140	2.278	44.75	53.64	31.87
.20 sand	0.150	2.860	50.67	47.33	45.52
.25 sand	0.151	2.863	50.49	47.48	68.29

Increasing Hf thickness increases costs for diminishing returns in sensitivity

Keno V.a Scoping Calculations Conclusions

- 0.10 cm Hf selected as optimal thickness
  - Can create assemblies in all 3 energy spectrums with compact cores
  - Increased Hf thickness does not provide great advantage and increases costs
  - Final design should use both stacking methods
    - Standard stacking has greater sensitivity in fast and intermediate regions
    - Sandwich stacking has greater sensitivity in thermal regions

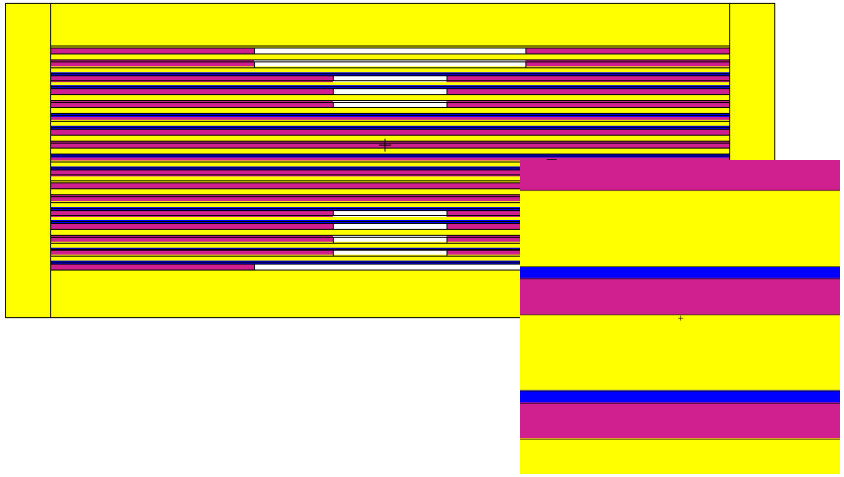
Potential Issue- HEU Jemima Plate Inventory

Plate Type	OD (in) nominal	ID (in) nominal	Thickness (in)	Available
Solid Disk*	15	-	0.12	5
6 wedges*	15	-	0.12	1
Disk with central 2.5” hole	15	2.5	0.12	7
Disk with central 6” hole*	15	6	0.12	7
6” disk*	6	-	0.12	1
Disk with central 10” hole	15	10	0.12	8

*Seven complete disks can be made from parts

Realistic Jemima Models

- Models developed with MCNP5 using ENDF/B-VII.1 continuous energy cross sections
- Use 0.1 cm thickness Hf plates
- Vary PE thickness from 1/16” to 1” in 1/16” increments
- Two stacking methods, Standard and Sandwich



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Detailed Plate Model Results

		Jemima Plates					
PE Thickness (in)	Stacking Method	Solid Disks	Disk w/ 2.5" hole	Disk w/ 6" hole	Disk w/ 10" hole	Height (in)	MCNP5 k_{eff}
0	Standard	7	7	6	7	6.252	1.0286
1/16	Standard	7	7	5	0	5.117	1.0174
1/8	Standard	7	7	3	0	5.677	1.0166
1/4	Standard	7	6	0	0	6.047	1.0070
3/4	Standard	7	1	0	0	8.299	1.0099
1	Standard	7	1	0	0	9.260	1.0220
1 1/4	Standard	7	1	0	0	11.010	1.0123
1/16	Sandwich	7	7	4	0	4.858	1.0109
1/8	Sandwich	7	7	2	0	5.356	1.0101
1/4	Sandwich	7	7	0	0	6.415	1.0167
3/4	Sandwich	7	4	0	0	10.193	1.0075
1	Sandwich	7	4	0	0	12.693	1.0039
1 1/4	Sandwich	7	7	1	0	20.823	1.0050

Detailed Plate Model Results- Fission Fractions

Standard Stacking Configurations

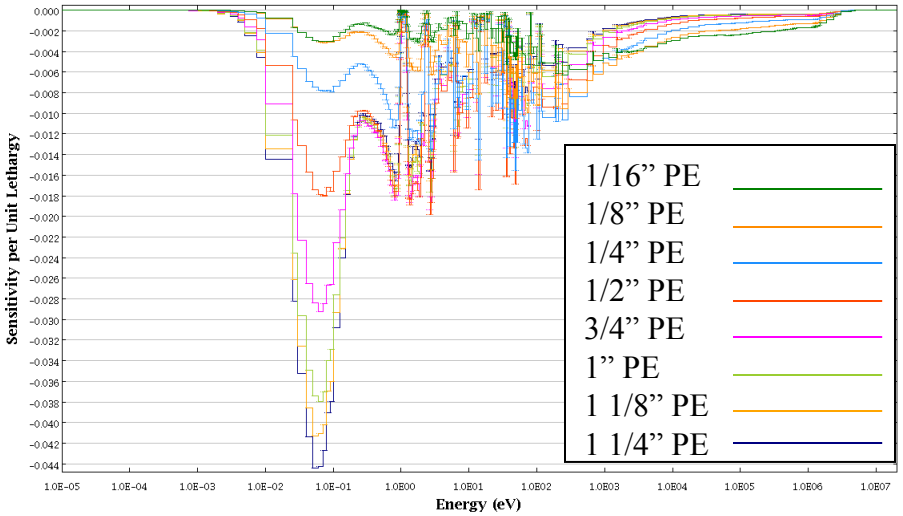
PE Thickness	Fast	Inter	Therm
0	0.7919	0.1629	0.0450
1/16	0.5399	0.4041	0.0554
1/8	0.4285	0.5008	0.0709
1/4	0.3134	0.5467	0.1395
3/4	0.1753	0.4097	0.2954
1	0.1520	0.3525	0.4952
1 1/4	0.1403	0.3129	0.5472

Sandwich Stacking Configurations

PE Thickness	Fast	Inter	Therm
0	0.7919	0.1629	0.045
1/16	0.5296	0.4037	0.0666
1/8	0.4204	0.5018	0.0784
1/4	0.3118	0.5647	0.1240
3/4	0.1787	0.4764	0.3442
1	0.1573	0.4209	0.4213
1 1/4	0.1434	0.3782	0.4788

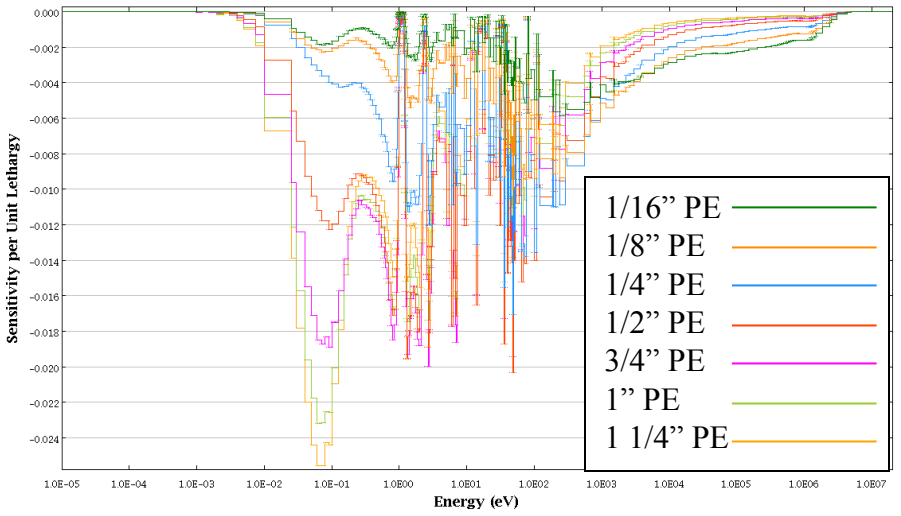
Hafnium Sensitivity- MCNP ENDF/B-VII.1*

Standard Stacking



Hf Capture	total	fast %	inter %	therm %
1/16	0.0504	0.0054	0.0334	0.0116
1/8	0.0653	0.0041	0.044	0.0173
1/4	0.0936	0.0028	0.0496	0.0412
3/4	0.1353	0.0014	0.037	0.0969
1	0.1427	0.0012	0.0311	0.1104
1 1/4	0.1467	0.0011	0.0265	0.1192

Sandwich Stacking



Hf Capture	total	fast %	inter %	therm %
1/16	0.0452	0.0051	0.0319	0.0081
1/8	0.0607	0.0039	0.043	0.0138
1/4	0.082	0.0026	0.0504	0.029
3/4	0.1206	0.0011	0.0421	0.0773
1	0.1188	0.0009	0.0359	0.082
1 1/4	0.1133	0.0007	0.0309	0.0817

* Calculations done by IRSN in support of TEX

Conclusions

- Thermal, intermediate, and fast assemblies are feasible with real Jemima plate geometries and 0.1 cm Hf plates
- Large differences between TSUNAMI 238 Group vs MCNP continuous energy sensitivity calculations
  - Up to 33% difference between the two codes
  - Some due to ENDF/B VII.0 vs VII.1
  - Mostly due to limitations of the multigroup data and inability to accurately perform resonance self-shielding calculations for the thin plate geometry
- MCNP sensitivity calcs confirmed utility of employing both stacking methods
  - Standard stacking has greater sensitivity in fast and intermediate regions and greater overall sensitivity
  - Sandwich stacking has greater sensitivity in thermal regions

Acknowledgements

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